2018 Annual Merit Review

Cummins/Peterbilt SuperTruck II

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Cummins Inc.

Ken Damon – Peterbilt Motors Company

21 June 2018

Project ID:ACS102

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

Begin: 10/1/2016

End: 9/30/2021

30% complete (03/18)

Barriers

Engine Efficiency ≥ 55% BTE

Freight Efficiency ≥ 100% FTE

Cost effective solutions

Budget

Total Project: $40M

$20M DoE - $20M Partners

Total Spent: $13.6M

$6.8 = Partners

$6.8 = DoE

Partners

Cummins – Powertrain

Eaton - Transmission

Peterbilt - Vehicle

Bridgestone – Tires

Walmart – Customer counsel

Objectives

- Demonstrate a *minimum* of 55% BTE at a 65 mph cruise, on an engine dynamometer test stand
  - Same engine systems also demonstrated in vehicle, operating on real world drive cycles
- Achieve a *minimum* of 125% Freight Ton Efficiency (FTE).
  - FTE = MPG*Tons of Freight
- Track, promote and report on cost effective solutions
  - Prioritize solutions that have ~3 year payback period
  - Utilize customer counsel for understanding payback variables

Relevance

- Approximately 20% of U.S. transportation petroleum goes to the production of heavy truck fuel. Proposed improvements would save more than 400 million barrels of oil per year.*
  - Reduce imports and improve energy security
  - Reduce the cost of moving goods
- Heavy Truck GHG emissions account for a CO2 equivalent 420.7 MMT per year (35th edition of the Transportation Energy Data Book).
  - Improved air quality
  - Protect the public health and environment

* https://energy.gov/eere/vehicles/vehicle-technologies-office-moving-america-forward-energy-efficient-vehicles

Technical Approach
– Collaborations –

Metalsa
Quality as a way of life
OAK RIDGE National Laboratory
ALCOA
Bergstrom
Climate Control Systems
BRIDGESTONE
Prestolite
PURDUE UNIVERSITY
MAHLE
MERITOR
Stoneridge
BRAMMO
BorgWarner
HENDRICKSON
The World Rides On Us
NREL
EATON
Powering Business Worldwide
Great Dane
IMI NORGREN

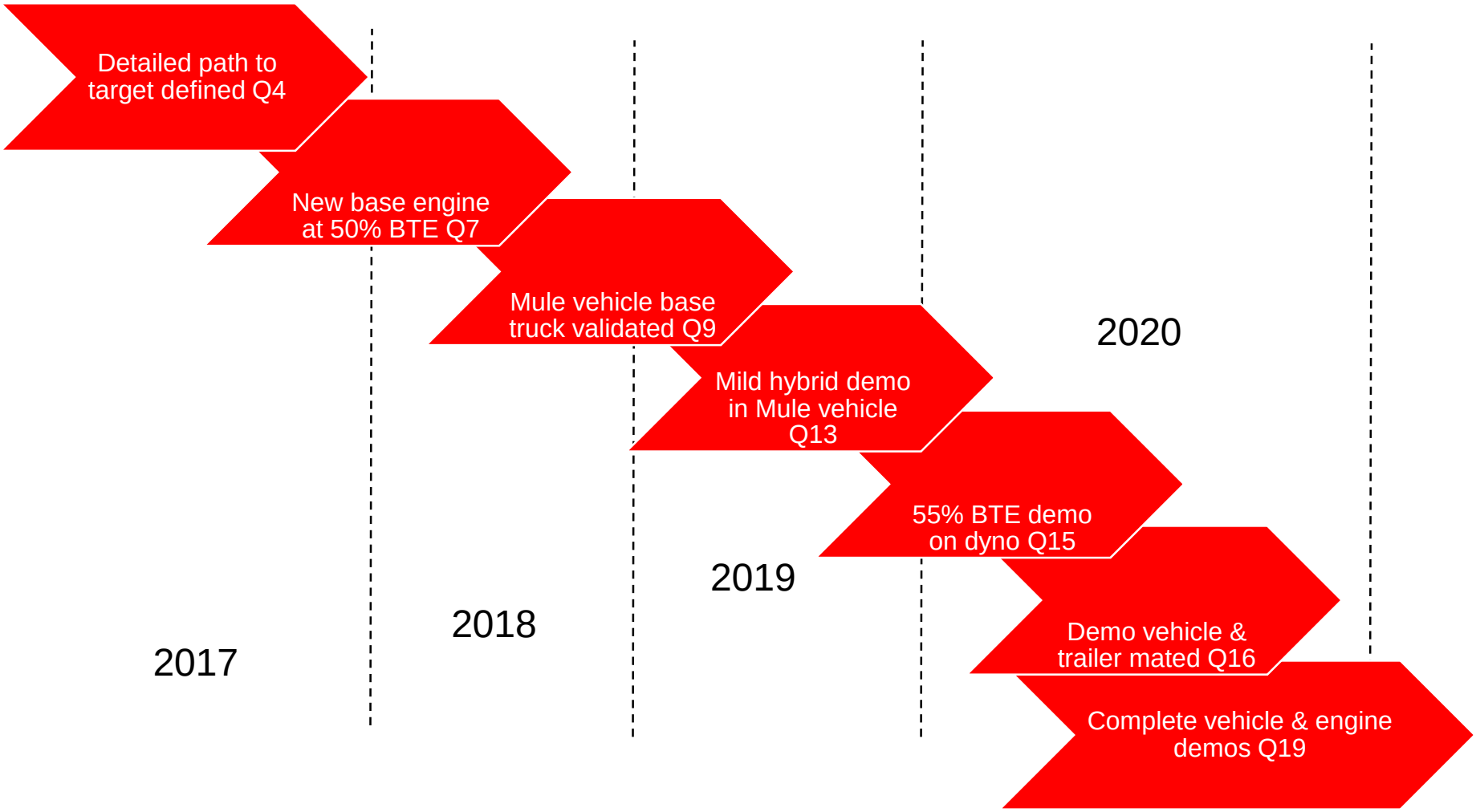
Milestones by Quarter

FY 2018	Description
✓ Mule tire samples built	Tire samples built and tested, model data confirmed and included in overall system model
✓ Weight budget confirmed	Chassis, cab/sleeper, trailer and powertrain targets established
Base engine at 50% BTE	Dynamometer demonstration of base engine at 50% BTE
Cooling system direction confirmed	Cooling system simulation with various routes and ambient conditions

Milestones by Quarter

FY 2019	Description
Final Cd via simulation, confirmed	Final adjustment required for produce ability of prototype hardware
Tire RRC confirmed/tested	On-Road/Rig data
ACEM Features selected	Inertia restart, Coasting feature, weather, etc included in mule testing and validation
HHRR combustion system and Low voltage hybrid	New combustion system for final demonstration and 12/48V system for energy recovery

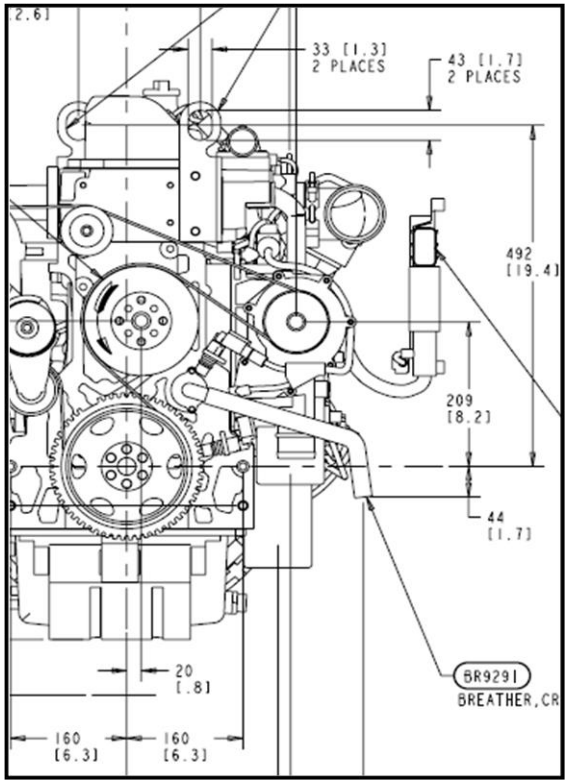
Program Milestones



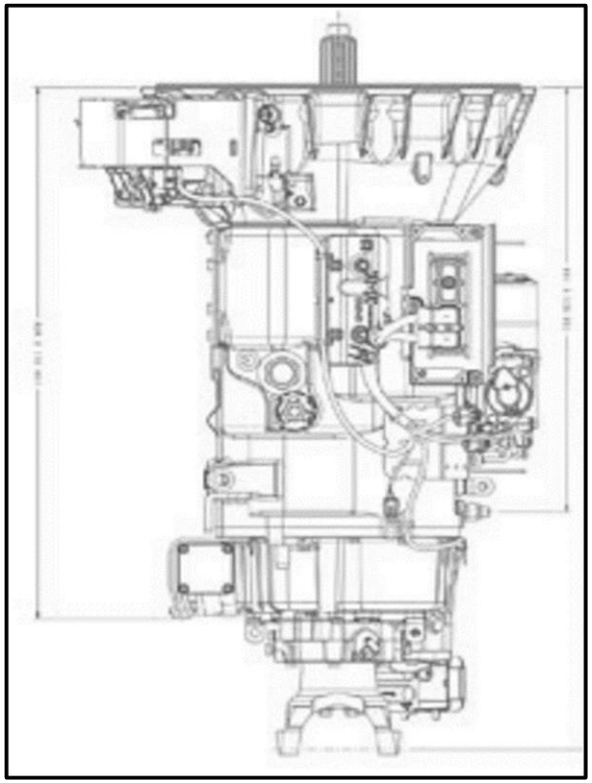
All proposed future work is subject to change based on funding levels

Cummins Powertrain

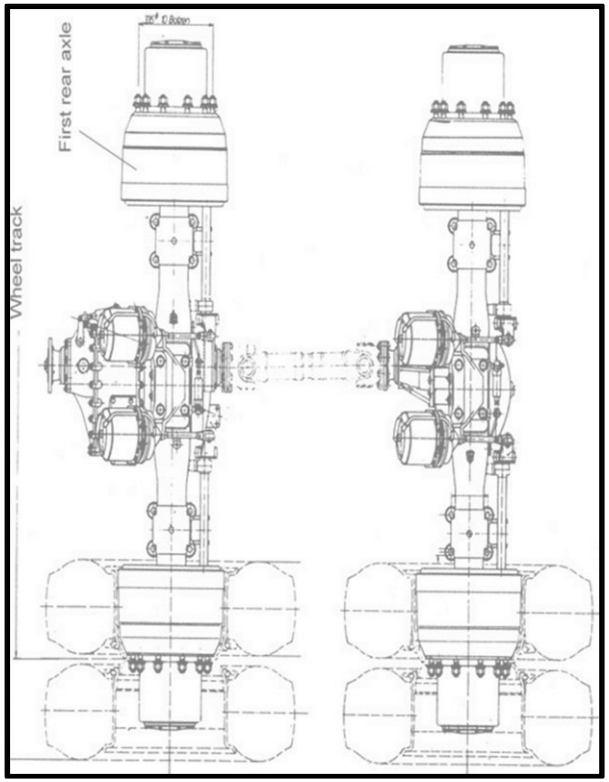
ENGINE



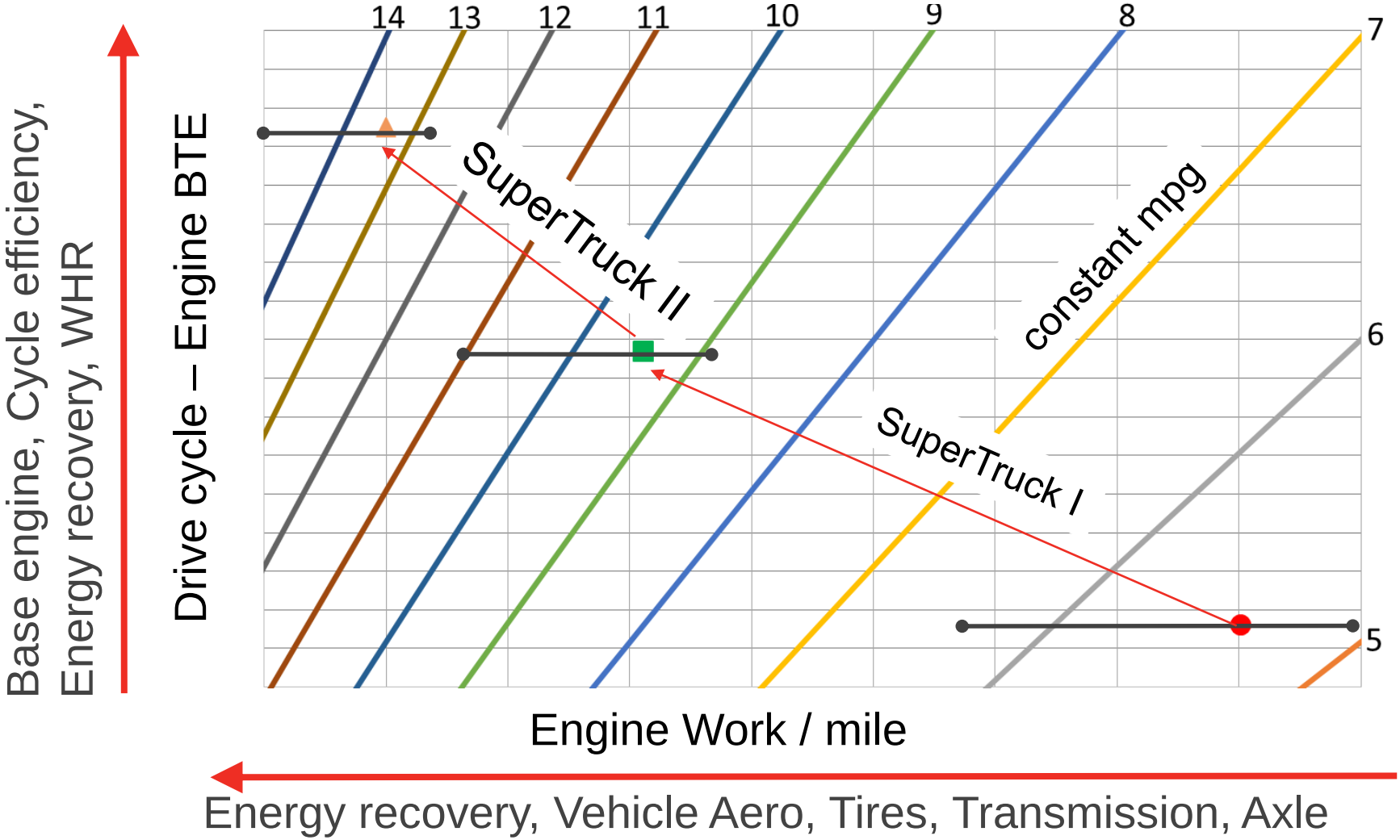
TRANSMISSION



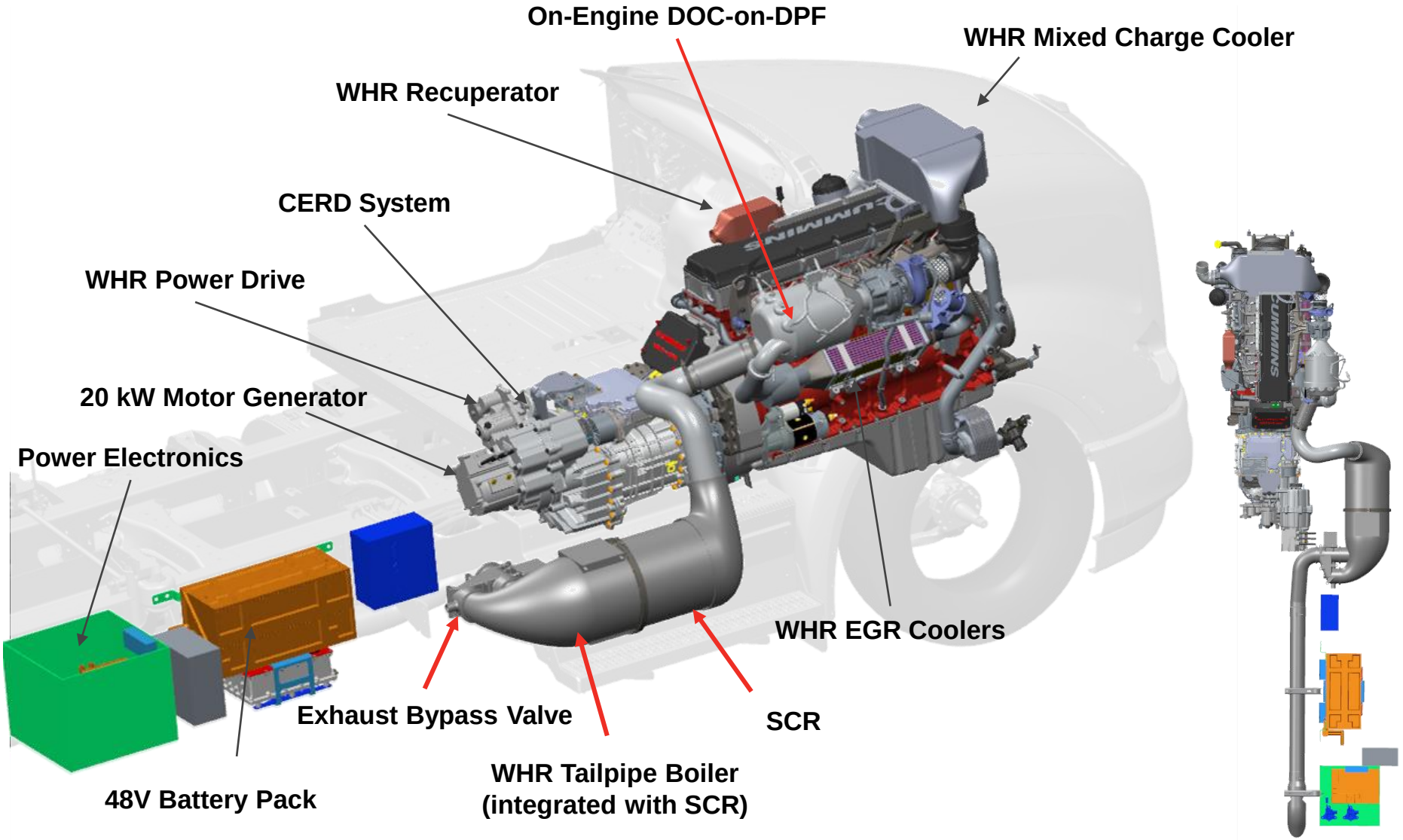
DRIVE AXLE



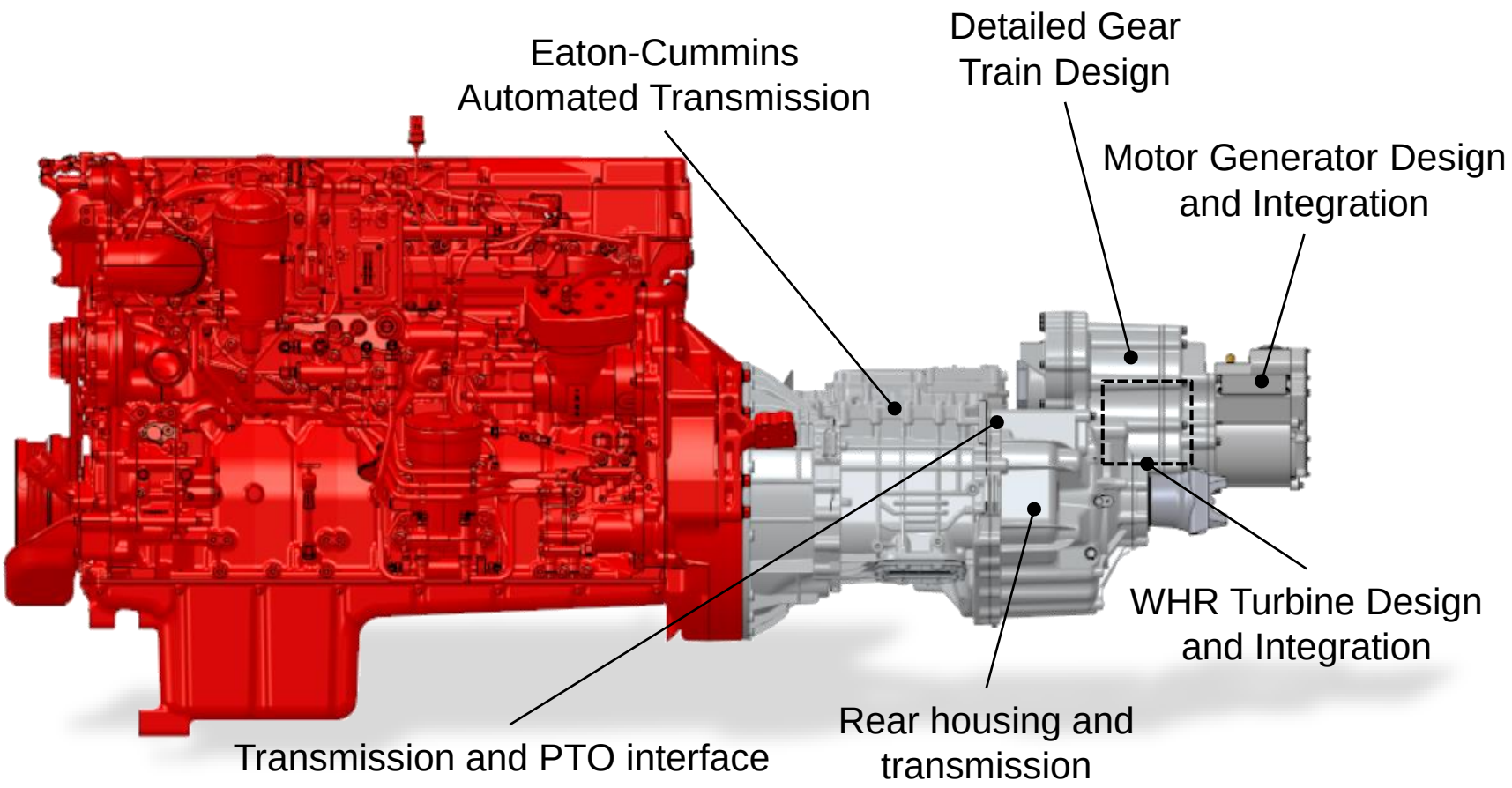
Technical Approach
– SuperTruck II Target –



Accomplishments
Powertrain Integration



Accomplishments
Cummins Energy Recovery Drive (CERD)



A seamlessly integrated, high efficiency, reliable, hybrid powertrain package

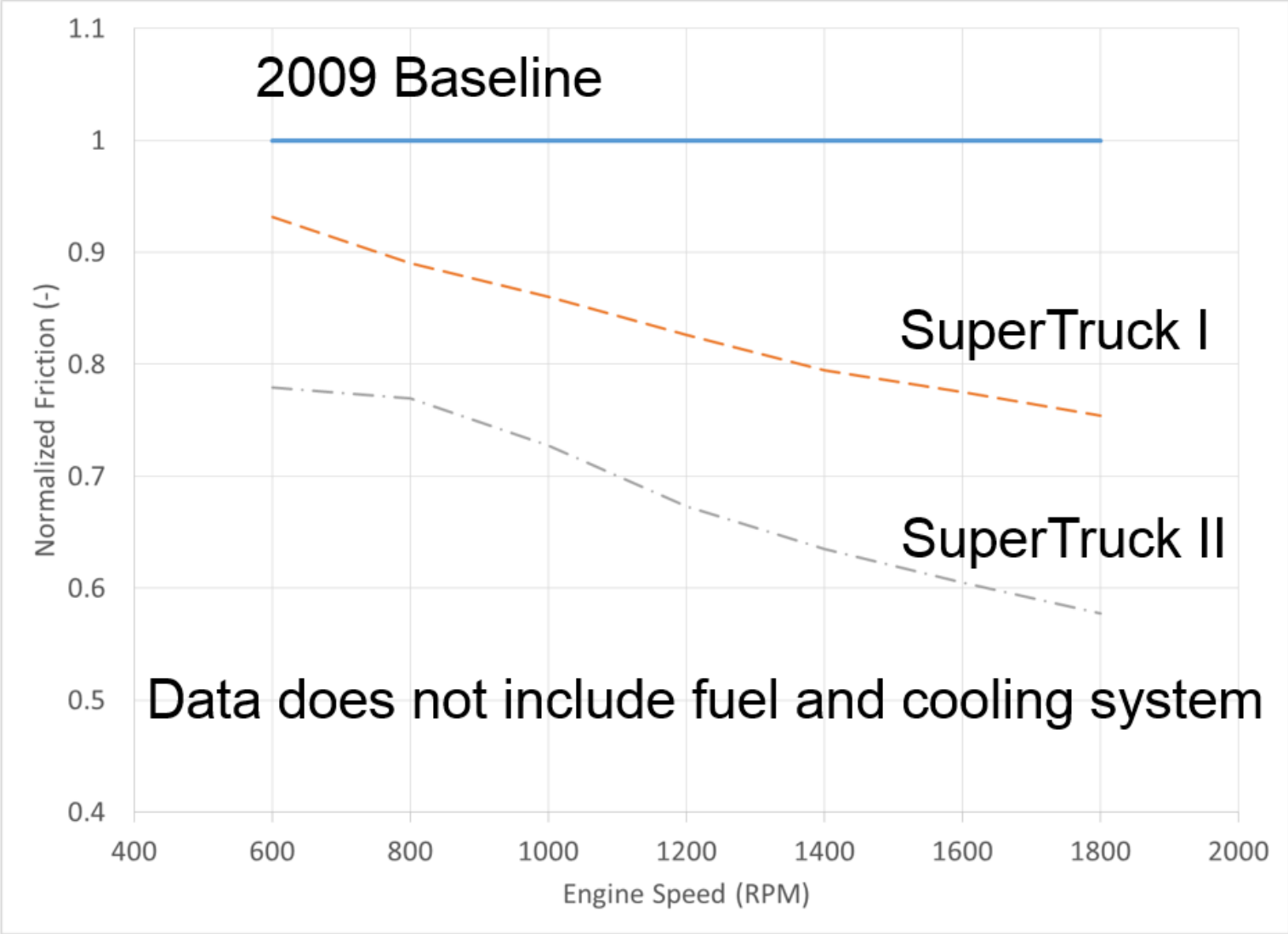
Accomplishments
Progress toward 50% BTE Milestone

<u>New Platform Engine, without WHR system</u>

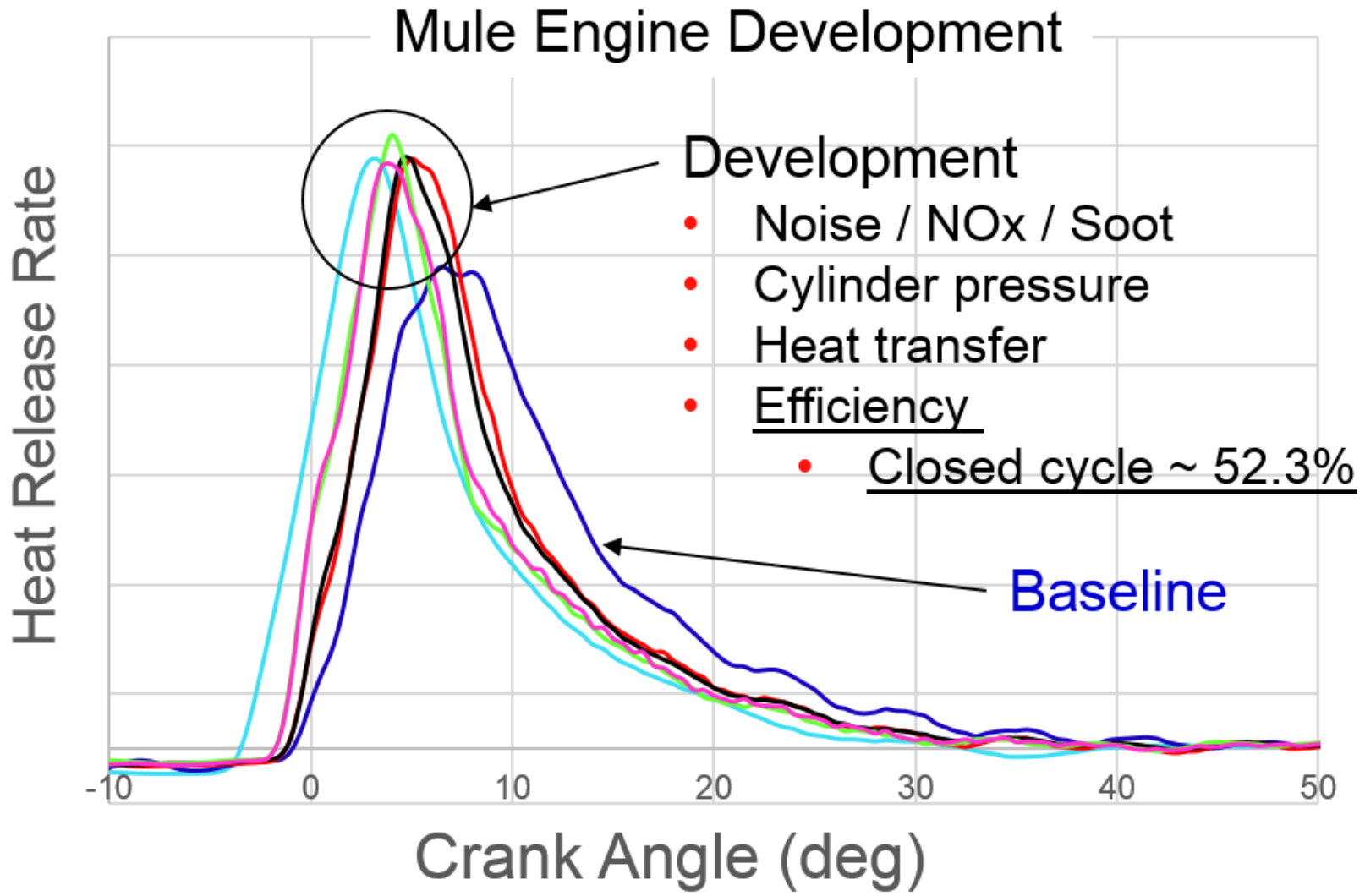
- Target Mech Eff'y = 94.7% Closed Cycle = 53% Open Cycle = 100%
- April 2018 status (47.8%)
  Mech Eff'y = 94.1% Closed Cycle = 51.4% Open Cycle = 98.8%
- Technology yet to be applied
  - Variable oil pump
  - Variable coolant pump
  - High Heat Release Rate fuel system
  - Increased Compression Ratio
  - Low Friction Rings
  - Conversion to LP EGR configuration
    - Fixed geometry turbine
    - Elimination of HP EGR requiring engine dp

Accomplishments

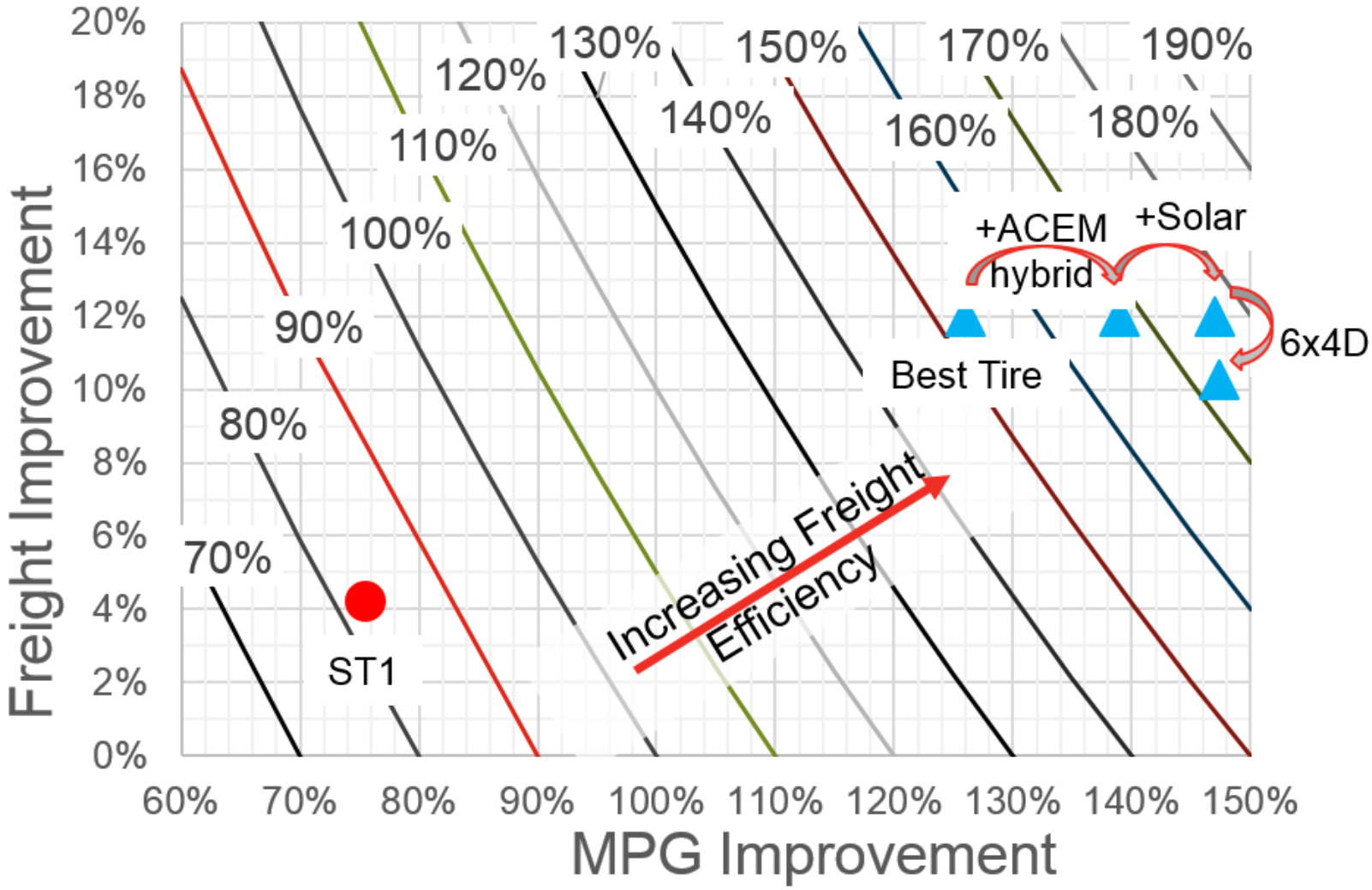
Engine System Friction Reduction



Accomplishments
Closed Cycle Efficiency (CCE)

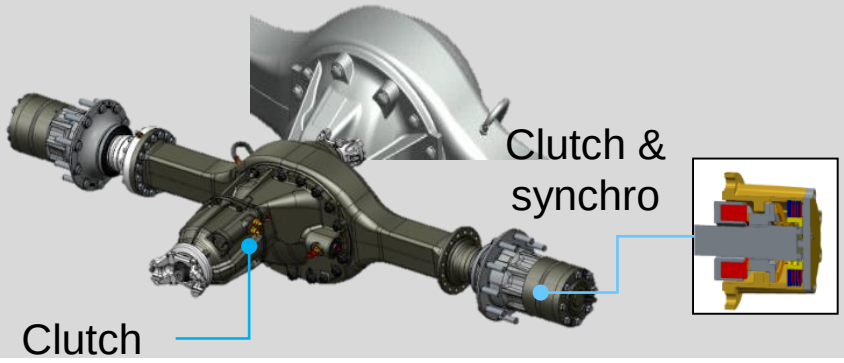


ST2 Freight Efficiency Powertrain Path-to-Target



Accomplishments
Disengage-able Tandem Technology

TECHNOLOGY OVERVIEW



FEATURES & BENEFITS

Efficiency	0.4% Fuel Economy improvement vs base
Gradeabilty	38% Dry; 27% Wet
Weight	Minimal weight impact anticipated
Up Time	1.2M mi target B10 life

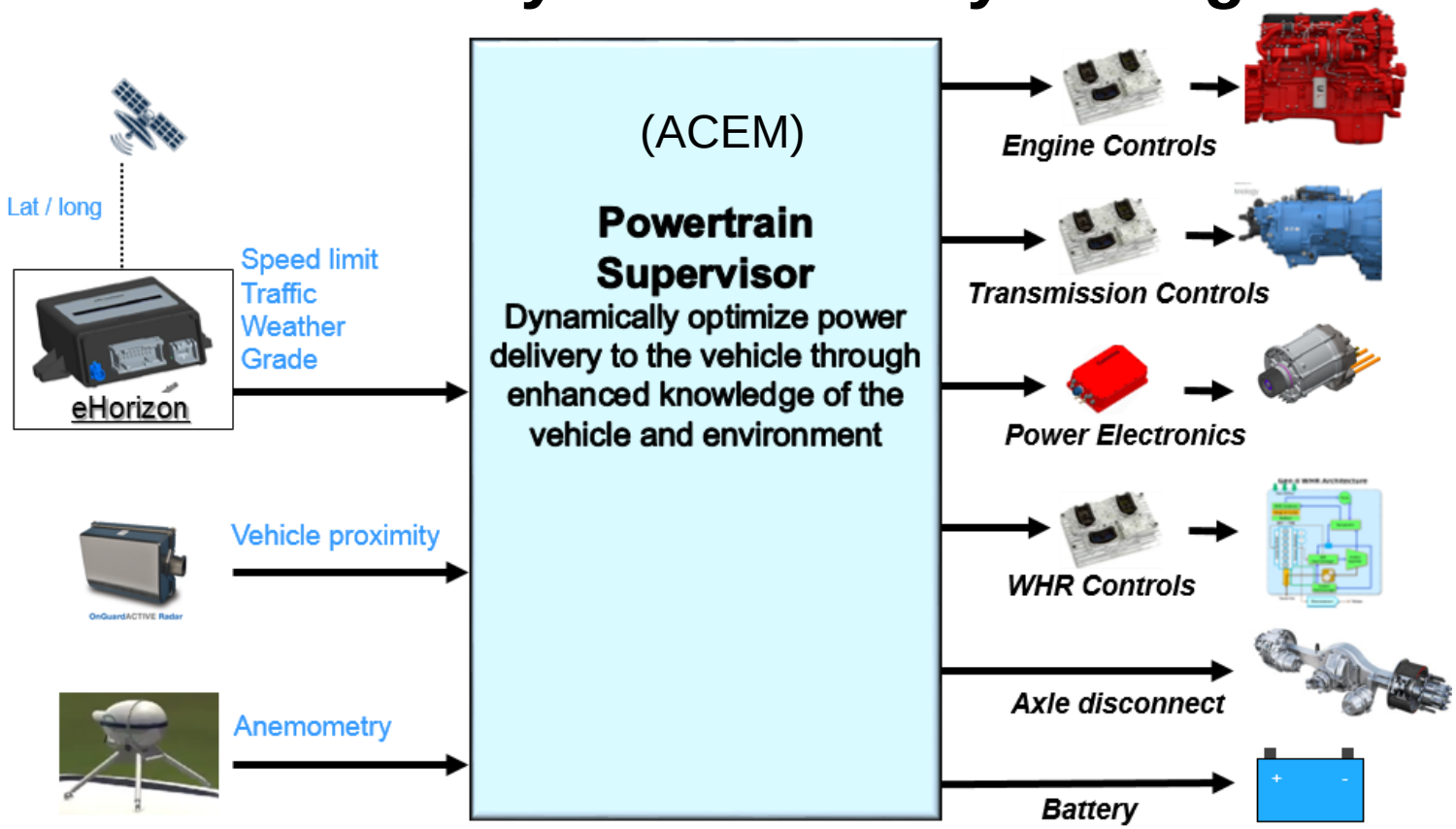
TECHNOLOGY/DEVELOPMENT DETAILS

- Technical Description
  - Traction in low speed operation
  - Disengages forward pinion and axle shafts at highway speed
  - Eliminates forward axle churning and gear losses
  - Accommodates “fast” ratios (<2:1)
  - Overrides for weather conditions
  - Lightweight aluminium components
  - Customer acceptance vs 6x2
- Development Timeline
  - Mule build for road test mid-2018
  - On road development 2019
  - Demonstration vehicle build 2020

slide courtesy Meritor

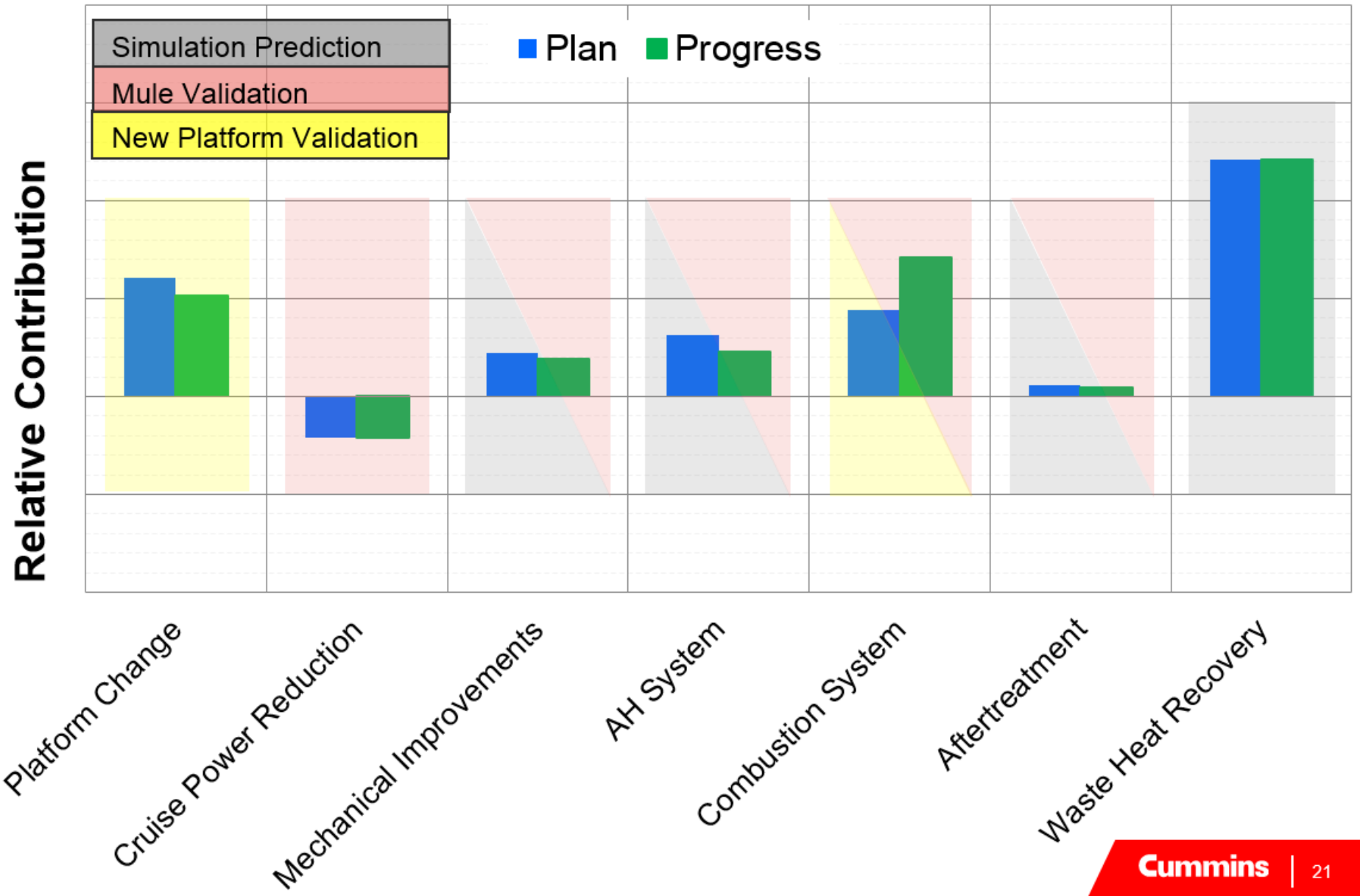
Accomplishments

Advanced Cycle Efficiency Manager



- Serve as the Powertrain Supervisor
  - coordinates the vehicle cruise speed
  - transmission power paths
  - engine on/off state
- Dynamically optimize commands to power producers (engine, waste heat recovery, electric machine)
- Manages battery system

Accomplishments
BTE Path to Target



Proposed Future Research

- Technology application costing
  - Printed part technology applications for low heat transfer piston and cylinder kit engine testing
  - Design and manufacturing alternatives for low heat transfer components
- LP EGR control strategy for FE/NOx optimization
  - Controller logic development for an inner and outer loop control strategy – transient performance and FE
- Mild hybrid system optimization
  - Continued simulation work for operating controls
  - Powertrain mule for road testing for added opportunities

All proposed future work is subject to change based on funding levels

Ken Damon

Peterbilt Motors

Technical Approach
– Enabling Technologies –

Driver Assist

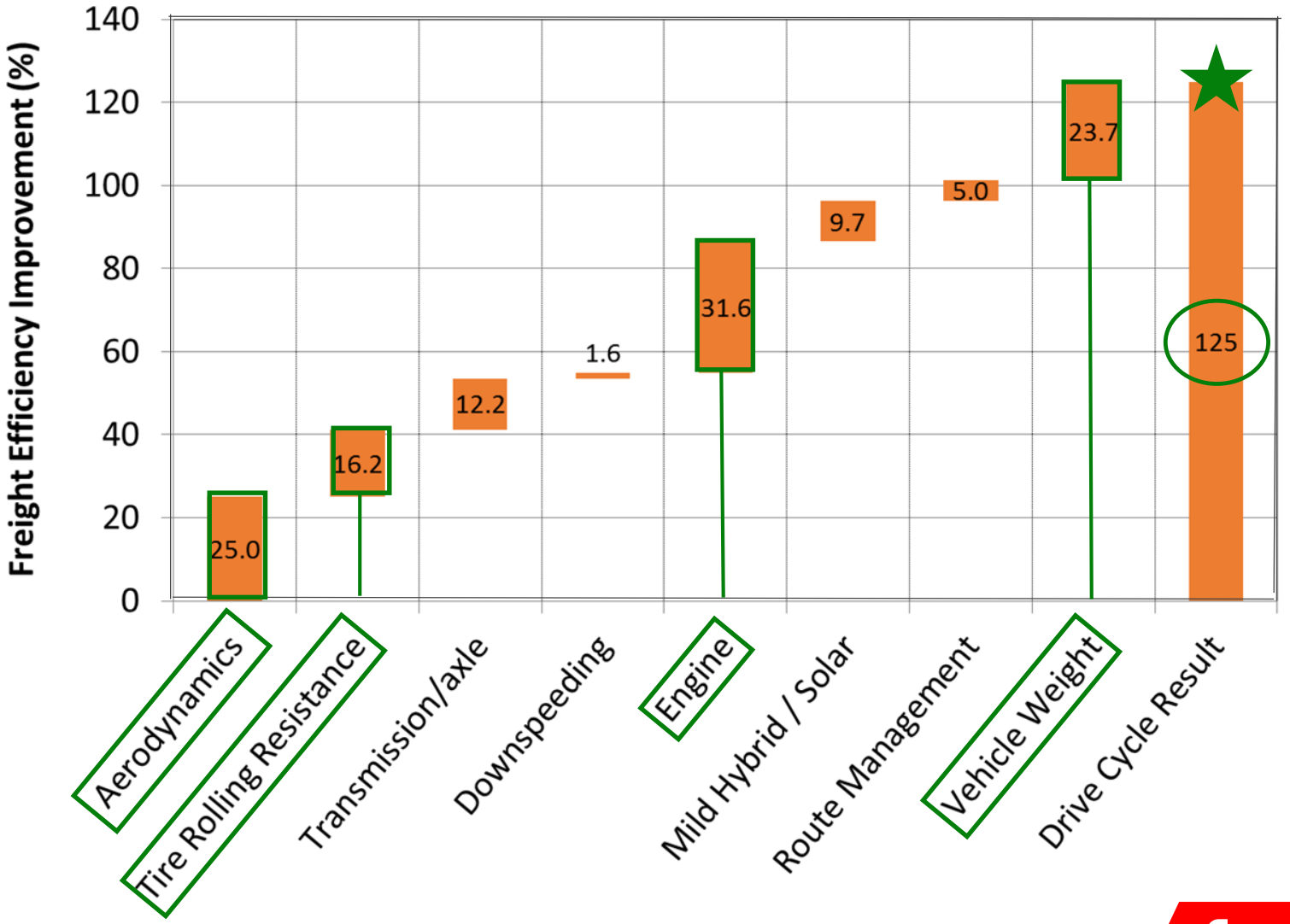
Powertrain Efficiency

Parasitic Reduction

Aerodynamics

Lightweighting

Accomplishments
– Path To Freight Efficiency Target –



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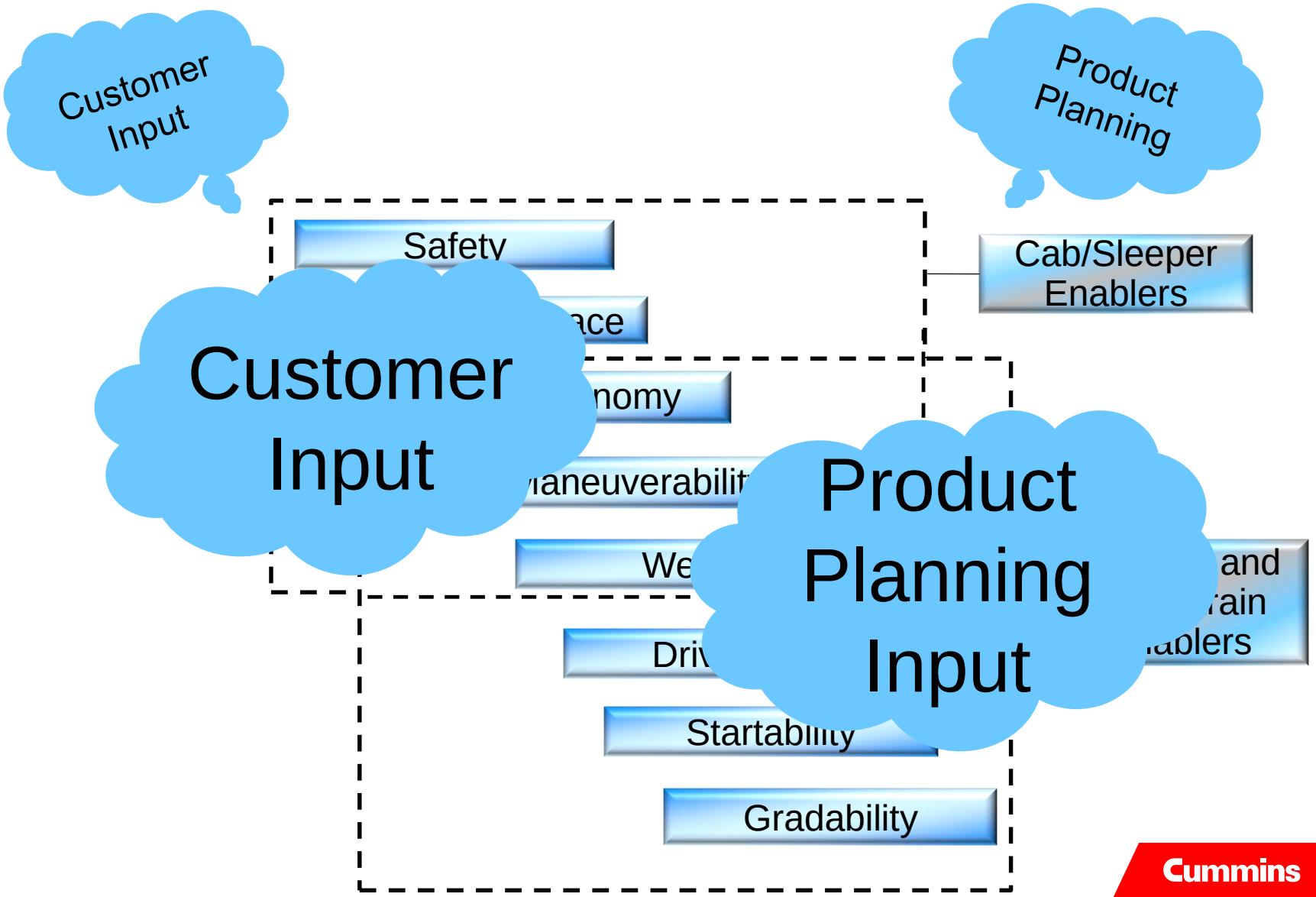
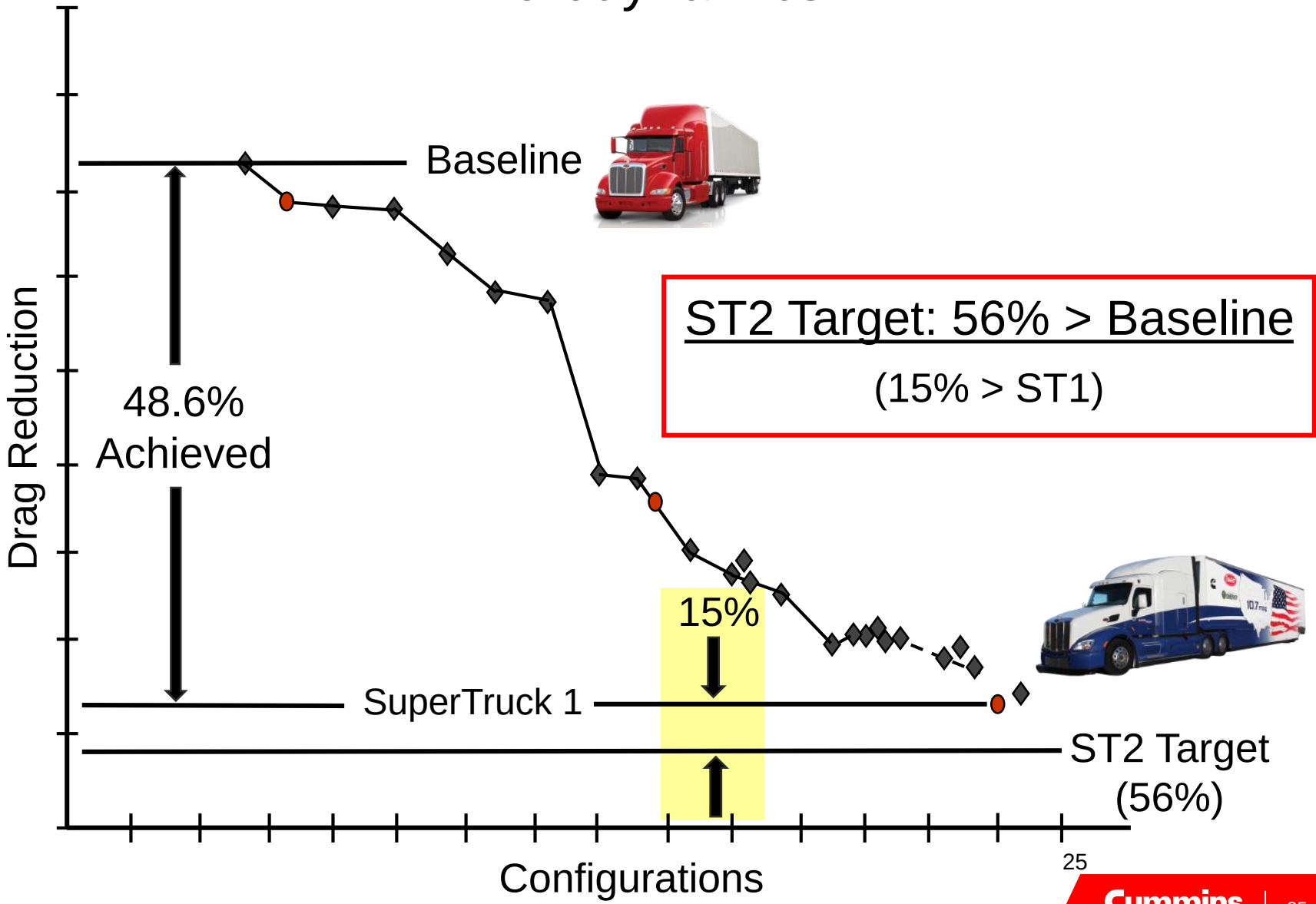
Technical Approach
– End User Empathy –



Technical Approach
– Aerodynamics –

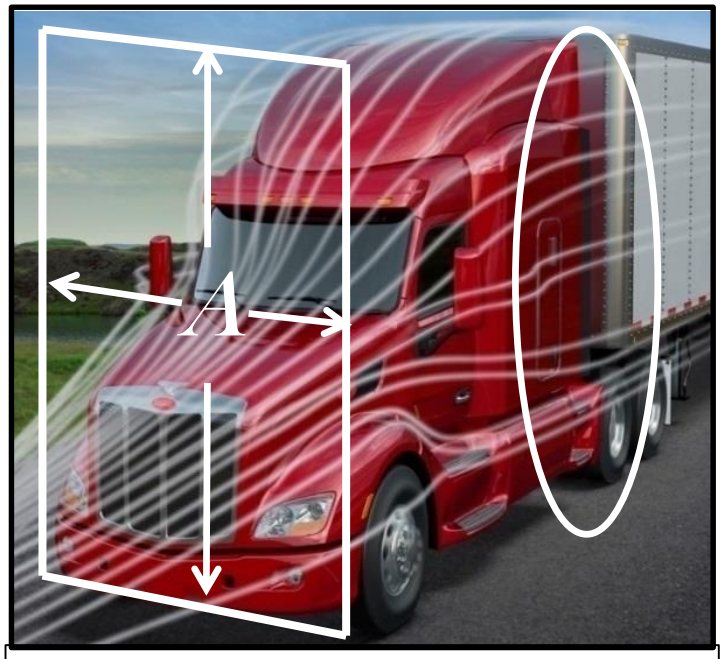


ST2 Target: 56% > Baseline

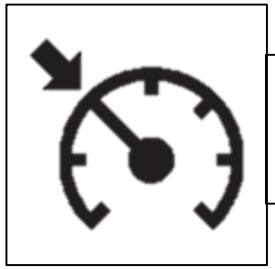
(15% > ST1)

Technical Approach
– Aerodynamics –

- Advanced Vehicle Shape
- Reduced Vehicle X-Section
- Trailer Gap Treatment
- Yaw Mitigation Techniques
- Advanced Speed Control



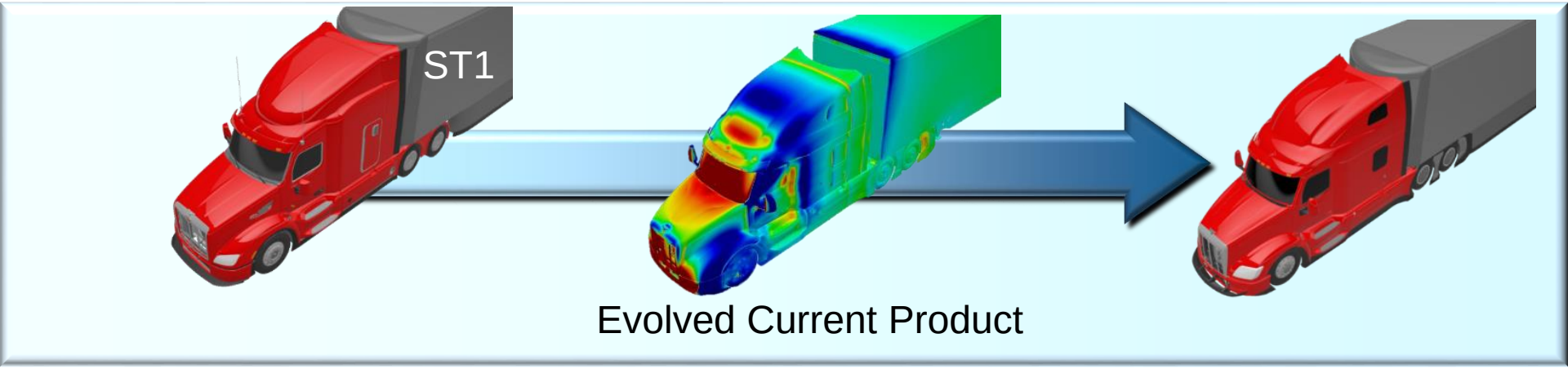
Outer Body Technologies



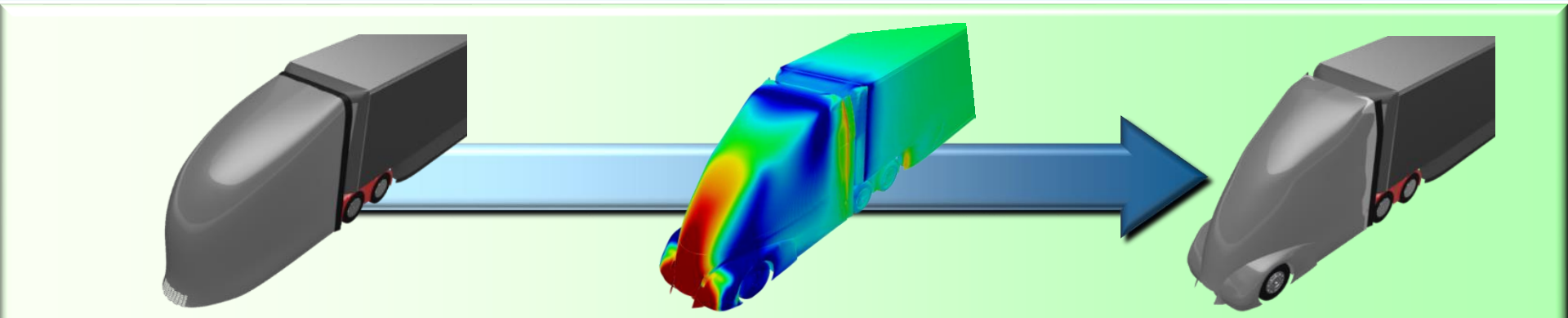
Advanced
Speed Control

Technical Progress
– Advanced Vehicle Shape –

- 15% Drag Reduction Goal (vs. ST1)
- 20% Improvement Analytically Achieved; Theme Selected
- 5-10% Bonus Opportunity Under Evaluation



Evolved Current Product



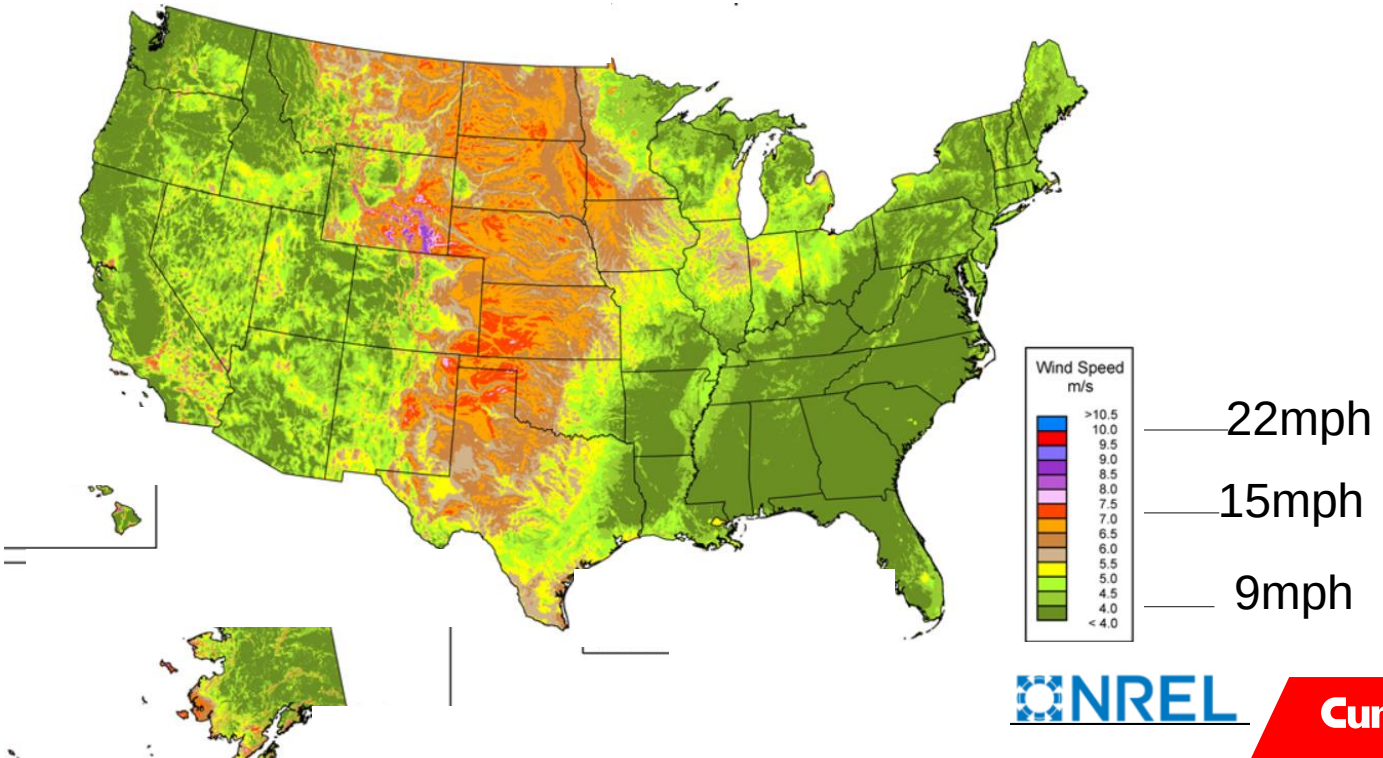
Clean Sheet Embodiment

Technical Progress
– Reduced Vehicle X-Sect –

- Tractor/Trailer Suspension Lowering at Speed
- Improved Drag Profile and Ground Sealing
- Targeting 4” Height Delta
- Achievement is on Track

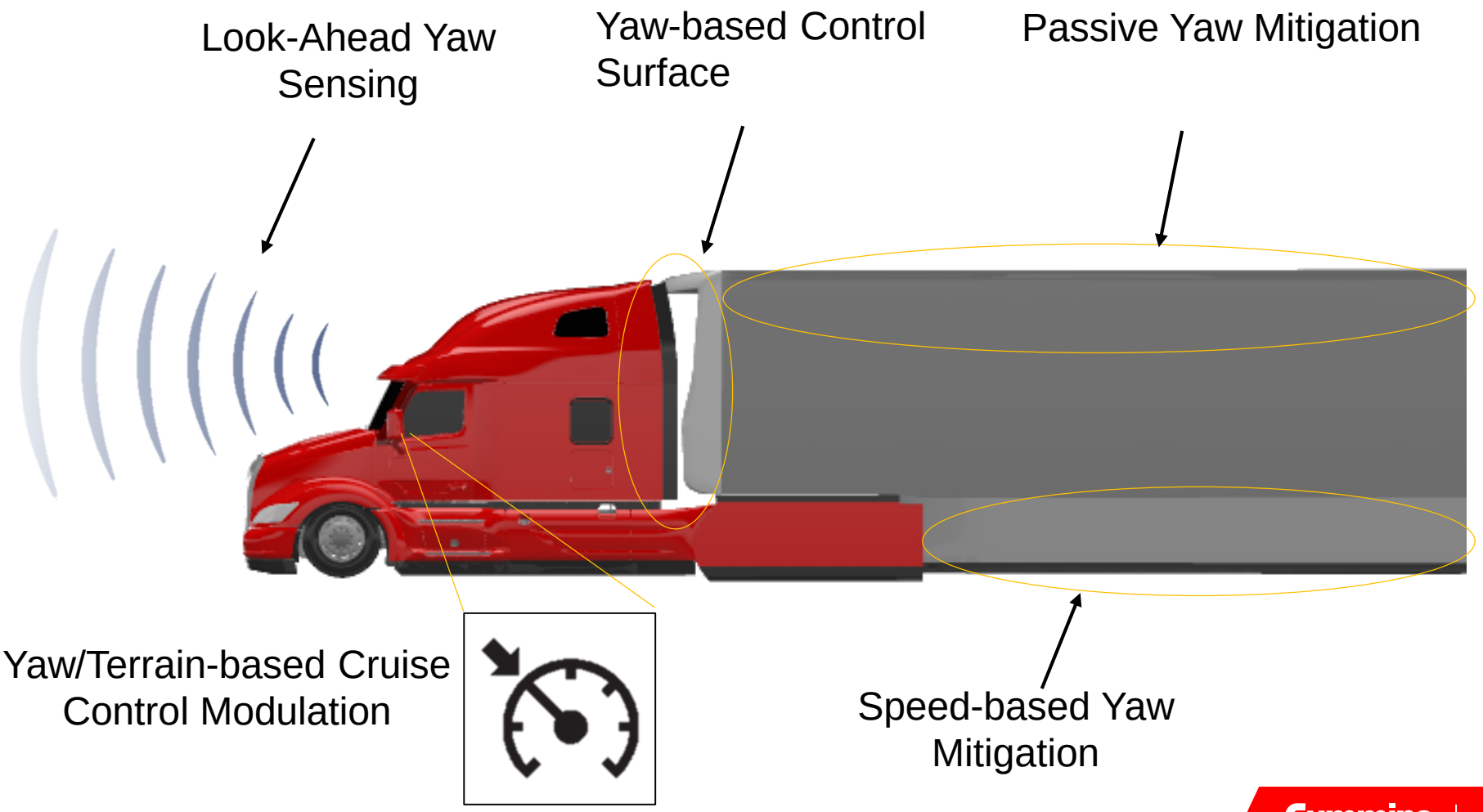
Technical Progress
– Trailer Gap, Yaw Mitigation –

- Drag Evaluation Commonly at 0 and 6º
- 6º Equates to ~7mph Crosswind
- Significant Areas of Country Well Above 7mph



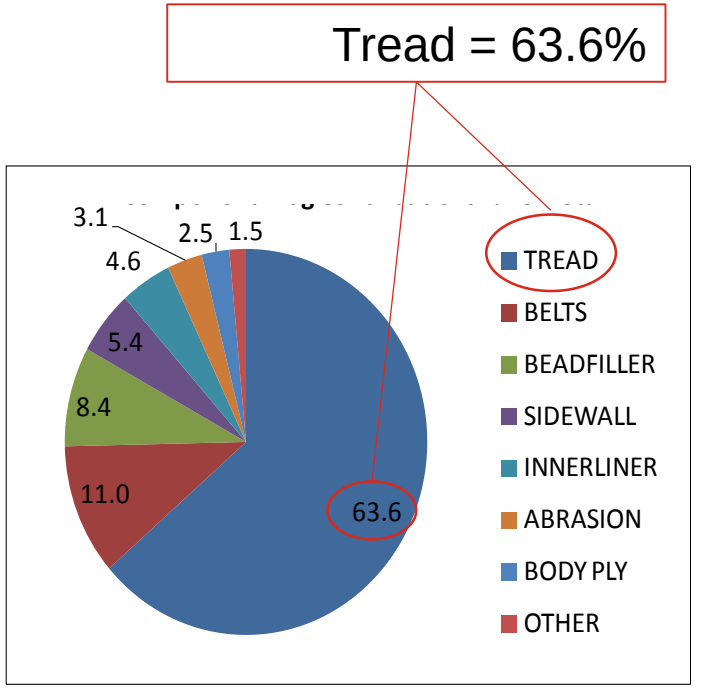
NREL

Technical Progress
–Yaw Mitigation, Speed Control –



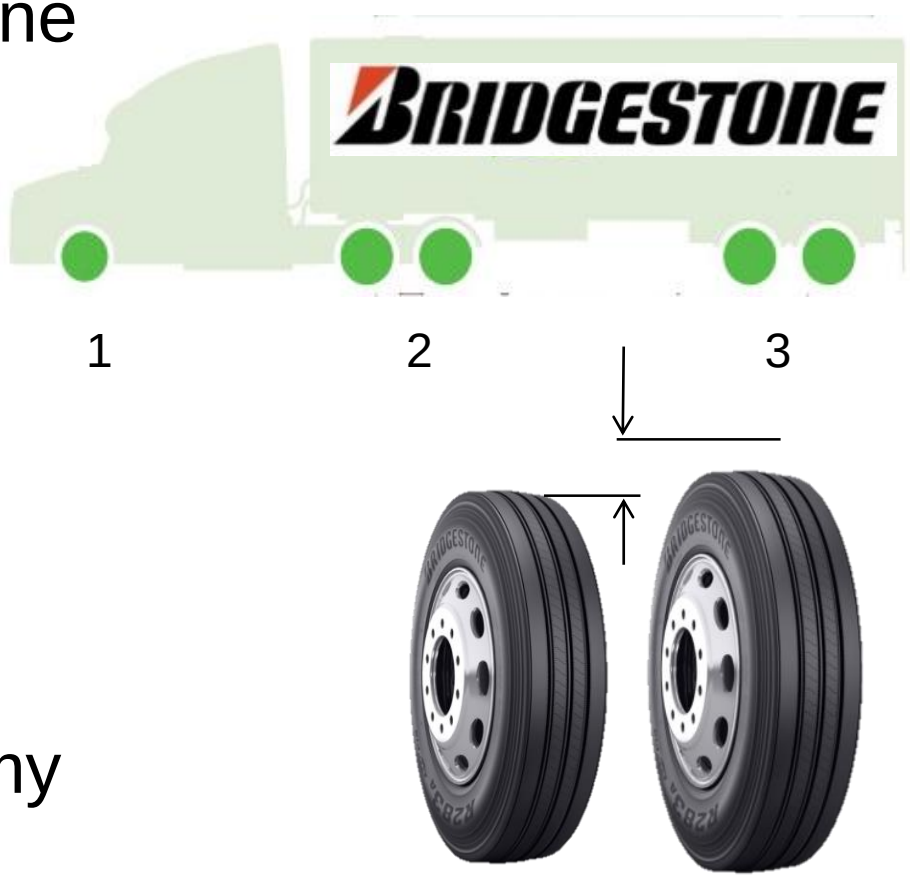
Technical Approach
– Parasitic Loss Reduction –

- Tires are 48% of ST1 Motoring Losses
- Majority of Losses via Tread
- Improve Rolling Resistance (Crr)
  - Reduced Strain from Tread Distortion
  - Losses via Deformation and Recovery Energy
  - Optimized Tread Volume
  - Alternate Tire Size



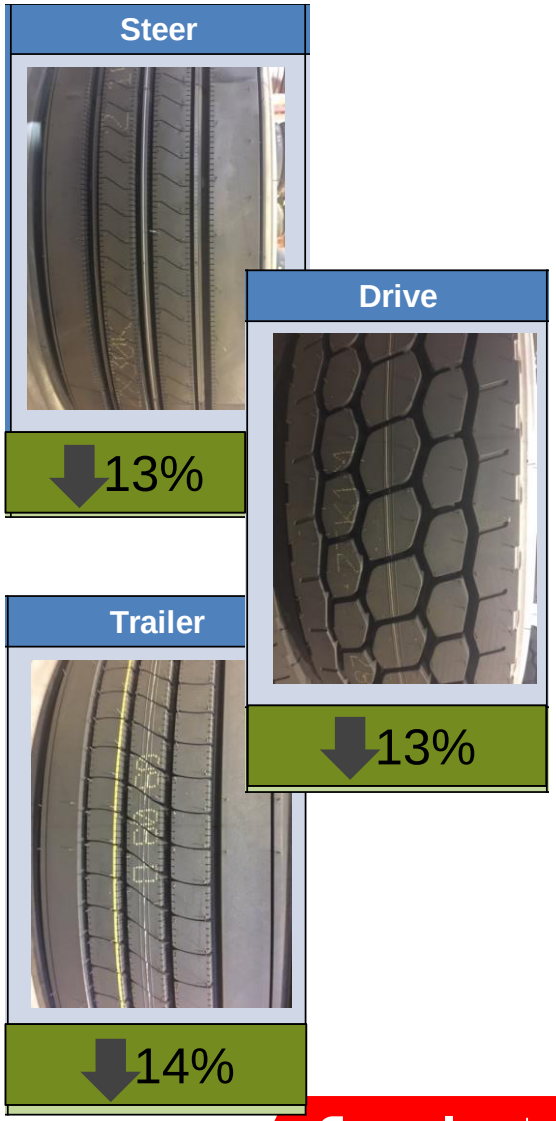
Technical Approach
– Parasitic Loss Reduction –

- Partnership with Bridgestone
- Three Tire Positions
  - (1) Steer
  - (2) Drive
  - (3) Trailer
- Tire Technology for Duals
- 30% Crr Reduction Target
- 6% Improved Fuel Economy
- Tire Size Evaluation



Technical Progress
– Parasitic Loss Reduction –

- Mule Tires Developed
  - 50% to Crr Target
- New Tread Pattern Complete
  - Improved Crr
  - Wear Paradigm
- Final Tire Size Selected
  - 285/75R24.5 (Baseline: 295/75R22.5)
  - 2” Larger Wheel Diameter
- Demo Tire Compound Technologies
  - 10% Additional Crr Reduction
- Initiated Patterns for Demo Tires



Technical Approach
– Trailer Development –

- Integrated Trailer Solutions
- 2000lb Reduction vs. Baseline
- Truck/Trailer Aerodynamic System
- Passive and Active Aerodynamic Enablers
- Designs Vetted w/ Customer Counsel

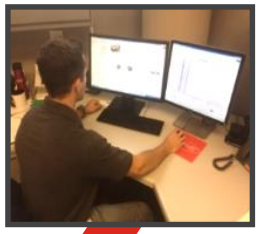
Great Dane

Technical Progress
– Lightweighting (vs. Baseline) –

System	Weight Delta (lbs)
Powertrain/Cooling	(285)
Chassis Systems	(1540)
Outer Body	(150)
Energy Storage	(615)
Trailer	(2095)
TOTAL	**(4685)**

Commercial Focus

- Develop
  - Focus on Technology Vetting
  - Integrate into Demonstration Vehicle
  - Feed Product Development Pipeline
- Harvest
  - Deploy Features/Options
  - Robust/Competitive Product Profile
- Deliver
  - Regulatory Compliant Products
  - High Value for the Market



Comments from 2017

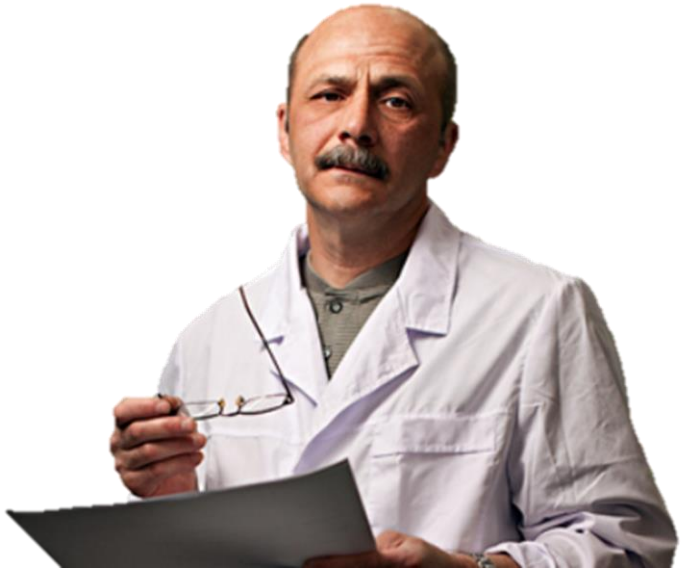
- Has the team considered the use of Ultra Capacitors for the Energy Storage System Aerodynamic Drag Ahead of Target?
- Answer: Yes, Ultra Capacitor will be our prime start source.

- Why was WHR benefit only 0.2% BTE?
- Answer: WHR total benefit to BTE will be greater than 4%. The arrangement used in SuperTruck II will be at least 0.2% greater than what was used on Cummins previous projects.

- Is Purdue a partner on the Cummins/Peterbilt SuperTruck 2 project?
- Answer: Purdue is a supplier for the project. Purdue is building a vehicle model in Autonomie in order to have a traceable model for partners and suppliers to vet technology options.

Program Summary

- Powertrain
  - Engine development on plan toward BTE targets
  - Powertrain Targets on Plan to meet FTE
  - Technology in Place for Successful Mule Vehicle Build
- Vehicle
  - Outer Body Theme Selected
  - Aerodynamic Drag Ahead of Target
  - Mule/Technology Truck Build Scheduled (August 2018)
  - Mule Tires Built; 50% to Final Crr Target
  - Final Tire Size and Technology Path to Target Identified
  - Tractor/Trailer Lightweighting Ahead of Target
- Cummins and Peterbilt will deliver a minimum 125% FTE and 55% BTE!



THANK YOU!

QUESTIONS